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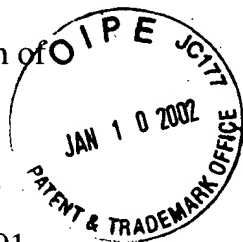
In re Patent Application of

STEELE et al

Serial No. 09/982,088

Filed: October 19, 2001

For: FUEL CELLS



Atty. Ref.: 550-282

Group:

Examiner:

\* \* \* \* \*

January 10, 2002

Assistant Commissioner for Patents  
Washington, DC 20231

**SUBMISSION OF PRIORITY DOCUMENTS**

Sir:

It is respectfully requested that this application be given the benefit of the foreign filing date under the provisions of 35 U.S.C. §119 of the following, a certified copy of which is submitted herewith:

Application No.

0026140.4

Country of Origin

United Kingdom

Filed

25 October 2000

Respectfully submitted,

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I also certify that by virtue of an assignment registered under the Patents Act 1977, the application is now proceeding in the name as substituted.

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GB0026140.4

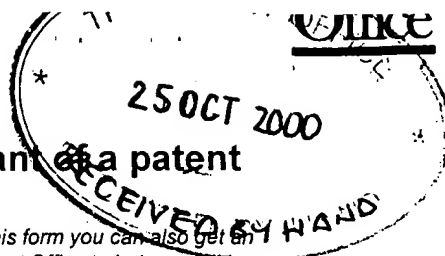
By virtue of a direction given under Section 30 of the Patents Act 1977, the application is proceeding in the name of:-

Ceres Power Limited  
90 Fetter Lane  
London  
EC4A 1JP  
United Kingdom  
Incorporated in the United Kingdom

ADP Number: 08243818001

# Request for a grant of a patent

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26 OCT 00 E578738-6 D02246  
P01/7700 0.00-0026140.4

The Patent Office

Cardiff Road  
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1. Your reference P008721GB KMB

2. Patent application number  
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0026140.4

3. Full name, address and postcode of the  
or of each applicant  
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IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY  
AND MEDICINE  
Sherfield Building  
Exhibition Road  
London  
SW7 2BX

25 OCT 2000  
SECTION 30 (1977 ACT) APPLICATION FILED 13.09.01

Patents ADP number (if you know it)

4033452001

If the applicant is a corporate body, give  
the country/state of its incorporation

United Kingdom

4. Title of the invention FUEL CELLS

5. Name of your agent (if you have one)

D YOUNG & CO

"Address for service" in the United Kingdom  
to which all correspondence should be sent  
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21 NEW FETTER LANE  
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59006

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applications, give the country and  
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Country

Priority application  
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11.

I/We request the grant of a Patent on the basis of this application..

Signature

Date

*Keith Boden*

**D YOUNG & CO**

Agents for the Applicants

25 Oct 2000

12. Name and daytime telephone number of person to contact in the United Kingdom

Dr Keith M Boden

023 80634816

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## FUEL CELLS

The present invention relates to fuel cells, and in particular intermediate-temperature solid oxide fuel cells (IT-SOFCs) which are typically used in stacks to generate a power output of from 1 to 100 kW and find application as local power generators, for example, in remote locations, such as for residential combined heat and power (CHP) generation, and in vehicles, either as a primary power unit (PPU), an auxiliary power unit (APU) or to drive other equipment, such as air-conditioning equipment.

For solid oxide fuel cells other than those integrated with a gas turbine, the fuel cells should be operated at the lowest temperature possible without compromising the electrode kinetics and electrolyte resistance.

Using known fabrication routes in the fabrication of ceramic electrolytes, it is generally accepted that the minimum film thickness that can be reliably fabricated is about 10  $\mu\text{m}$ . This minimum electrolyte thickness establishes a minimum operating temperature, typically about 650  $^{\circ}\text{C}$  for scandia-stabilised zirconia (SSZ) electrolytes, about 700  $^{\circ}\text{C}$  for yttria-stabilised zirconia (YSZ) electrolytes, and about 500  $^{\circ}\text{C}$  for doped ceria electrolytes, such as gadolinia-doped ceria (CGO) electrolytes. Further, the use of such a thin electrolyte film requires a substrate in order to provide a fuel cell having the necessary robustness.

For zirconia-based electrolytes, for example YSZ, a porous NiO-YSZ anode substrate typically having a thickness in the range of from 250 to 500  $\mu\text{m}$  is commonly used. Numerous techniques have been used to deposit electrolyte films on substrates. These techniques include screen printing, tape casting, vacuum slip casting, electrophoretic deposition, calendering, spray pyrolysis, sputtering and plasma spraying. In such fuel cells, the electrolyte film and the substrate are usually co-fired at high temperature, typically about 1400  $^{\circ}\text{C}$ , to ensure that the electrolyte film is dense and impermeable to gaseous molecules.

Whilst NiO-YSZ/YSZ structures have been successfully fabricated, the use of an NiO-YSZ substrate does give rise to a number of problems. These problems include poor thermal expansion compatibility, NiO-YSZ having a coefficient of thermal expansion in the range of  $12$  to  $13 \times 10^{-6} \text{ K}^{-1}$  as compared to  $10.6 \times 10^{-6} \text{ K}^{-1}$  for YSZ. NiO-Al<sub>2</sub>O<sub>3</sub> and NiO-TiO<sub>2</sub> substrates, which do have an improved thermal expansion match, are being developed, but these substrates still require a thin active interfacial layer of NiO-YSZ between the substrate and the electrolyte film to promote the electrochemical oxidation of the fuel. Another problem associated with the use of an NiO-YSZ substrate is the volume change associated with the reduction of the NiO component to Ni when in contact with the gaseous fuel. This volume change weakens the substrate and requires the fuel to be initially introduced very slowly into the stack to accommodate the volume change. Furthermore, with the use of an NiO-YSZ substrate, it is essential to ensure that the anode compartment remains sufficiently reducing so as to ensure that the Ni is not oxidised back to NiO, particularly during any cooling cycles.

Owing in part to the above-mentioned disadvantages of the ceramic NiO-YSZ substrate, the use of porous metallic substrates has been proposed, as disclosed, for example, in GB-A-1049428. The principal advantages of metallic substrates are recognised as the excellent mechanical behaviour and the improved electrical and thermal conductivity. However, the use of metallic substrates constrains the maximum fabricating temperature to about  $1000^\circ\text{C}$ , which temperature is below that required to sinter zirconia-based electrolytes into a dense impermeable film. Also, it is necessary to seal around the periphery of the porous substrate to prevent mixing of the gaseous oxidant and fuel. Currently, brittle glass, glass-ceramic or composite metal/ceramic seals are used for this purpose, which seals often crack during the thermal cycling experienced during operation.

As a consequence of the limitation to the fabrication temperature introduced by using metallic substrates, GB-A-1049428 discloses the use of plasma spraying to prepare dense films of zirconia-based electrolytes. Whilst plasma spraying can be used to deposit electrolyte films, that deposition technique is relatively expensive, in particular

being wasteful of the expensive ceramic powder. Other physical vapour deposition (PVD) techniques have also been used to deposit thin electrolyte films, but these techniques are also relatively expensive and not as convenient as the conventional ceramic processing routes. Chemical vapour deposition (CVD) techniques have also  
5 been used to deposit thin electrolyte films, but these techniques are still more expensive and likewise not as convenient as the conventional ceramic processing routes.

Alternative fuel cell designs have also been proposed, such as the circular fuel cell  
10 design as disclosed, for example, in US-A-5368667, US-A-5549983 and US-A-5589017. In this circular design, the gaseous oxidant and fuel are introduced via a manifold at the centre of the fuel cell stack, and the distribution and flow rate of the gaseous oxidant and fuel are arranged such as to ensure almost complete conversion of the fuel prior to reaching the periphery of the stack. With this design, only one brittle  
15 glass or glass-ceramic seal is required at the central manifold as the excess oxidant and fuel are combusted at the periphery of the stack. Although this fuel cell design represents an improvement, the brittle glass, glass-ceramic or composite metal/ceramic seal required at the central manifold is still liable to crack during the rapid thermal cycling experienced during operation.

20

It is thus an aim of the present invention to provide a solid oxide fuel cell and a method of fabricating the same which utilises a metallic substrate, enables the fabrication of a ceramic electrolyte film by sintering, and avoids the need to use brittle seals.

25

Accordingly, the present invention provides a solid oxide fuel cell, comprising: a ferritic stainless steel substrate including a porous region and a non-porous region bounding the porous region; a ferritic stainless steel bi-polar plate located over one surface of the porous region of the substrate and being sealingly attached to the non-  
30 porous region of the substrate about the porous region thereof; a first electrode layer located over the other surface of the porous region of the substrate; an electrolyte layer



located over the first electrode layer; and a second electrode layer located over the electrolyte layer.

5 Preferably, the ferritic stainless steel is a ferritic stainless steel containing no aluminium.

Preferably, the ferritic stainless steel is a titanium/niobium stabilised ferritic stainless steel.

10 More preferably, the ferritic stainless steel contains from about 17.5 to 18.5 wt % Cr (European designation 1.4509).

Preferably, the substrate has a thickness of from about 50 to 250  $\mu\text{m}$ .

15 More preferably, the substrate has a thickness of from about 50 to 150  $\mu\text{m}$ .

Yet more preferably, the substrate has a thickness of about 100  $\mu\text{m}$ .

20 Preferably, the porous region of the substrate includes a plurality of through apertures fluidly interconnecting the one and other surface of the substrate.

More preferably, the apertures are uniformly spaced.

25 Preferably, the apertures have a lateral dimension of from about 50 to 250  $\mu\text{m}$ .

More preferably, the apertures have a lateral dimension of from about 50 to 150  $\mu\text{m}$ .

Yet more preferably, the apertures have a lateral dimension of about 100  $\mu\text{m}$ .

30 Preferably, the apertures comprise from about 40 to 65 area % of the porous region of the substrate.

More preferably, the apertures comprise from about 50 to 55 area % of the porous region of the substrate.

5 Preferably, the substrate includes an active coating of an electronically-conductive oxide.

In one embodiment the active coating is a perovskite oxide mixed conductor.

10 Preferably, the perovskite oxide mixed conductor comprises  $\text{La}_{1-x}\text{Sr}_x\text{Co}_y\text{Fe}_{1-y}\text{O}_{3-\delta}$ , where  $0.5 \geq x \geq 0.2$  and  $0.3 \geq y \geq 0.1$ .

More preferably, the perovskite oxide mixed conductor comprises  $\text{La}_{0.6}\text{Sr}_{0.4}\text{Co}_{0.2}\text{Fe}_{0.8}\text{O}_{3-\delta}$ .

15 In another embodiment the active coating comprises doped  $\text{LaMnO}_3$ .

In one embodiment the substrate includes a recess in which the first electrode layer is at least partially located.

20 Preferably, the substrate comprises a foil.

Preferably, the substrate is a photo-chemically machined substrate.

25 Preferably, one or both of the first and second electrode layers has a thickness of from about 10 to 25  $\mu\text{m}$ .

More preferably, one or both of the first and second electrode layers has a thickness of from about 10 to 15  $\mu\text{m}$ .

30 Preferably, one or both of the first and second electrode layers is a sintered material.

In a preferred embodiment one of the first and second electrode layers comprises a sintered powdered mixture of perovskite oxide mixed conductor and rare earth-doped ceria.

- 5 Preferably, the powdered mixture comprises about 60 vol % of perovskite oxide mixed conductor and about 40 vol % of rare earth-doped ceria.

Preferably, the perovskite oxide mixed conductor comprises  $\text{La}_{1-x}\text{Sr}_x\text{Co}_y\text{Fe}_{1-y}\text{O}_{3-\delta}$ , where  $0.5 \geq x \geq 0.2$  and  $0.3 \geq y \geq 0.1$ .

10

More preferably, the perovskite oxide mixed conductor comprises  $\text{La}_{0.6}\text{Sr}_{0.4}\text{Co}_{0.2}\text{Fe}_{0.8}\text{O}_{3-\delta}$ .

- 15 Preferably, the rare earth-doped ceria comprises  $\text{Ce}_{1-x}\text{RE}_x\text{O}_{2-x/2}$ , where RE is a rare earth and  $0.3 \geq x \geq 0.05$ .

More preferably, the rare earth-doped ceria comprises  $\text{Ce}_{0.9}\text{Gd}_{0.1}\text{O}_{1.95}$ .

- 20 In a particularly preferred embodiment the one of the first and second electrode layers is the first electrode layer provided as a cathode layer.

In a preferred embodiment the other of the first and second electrode layers comprises a sintered powdered mixture of NiO and rare earth-doped ceria.

- 25 Preferably, the powdered mixture comprises about 50 vol % of NiO and about 50 vol % of rare earth-doped ceria.

Preferably, the rare earth-doped ceria comprises  $\text{Ce}_{1-x}\text{RE}_x\text{O}_{2-x/2}$ , where RE is a rare earth and  $0.3 \geq x \geq 0.05$ .

30

More preferably, the rare earth-doped ceria comprises  $\text{Ce}_{0.9}\text{Gd}_{0.1}\text{O}_{1.95}$ .

In a particularly preferred embodiment the other of the first and second electrode layers is the second electrode layer provided as an anode layer.

Preferably, the electrolyte layer has a thickness of from about 10 to 20  $\mu\text{m}$ .

5

In one embodiment the electrolyte layer comprises a sintered powdered mixture of rare earth-doped ceria and  $\text{Co}_3\text{O}_4$ .

Preferably, the sintered powdered mixture comprises about 98 mole % rare earth-doped ceria and about 2 mole %  $\text{Co}_3\text{O}_4$ .

10

Preferably, the rare earth-doped ceria comprises  $\text{Ce}_{1-x}\text{RE}_x\text{O}_{2-x/2}$ , where RE is a rare earth and  $0.3 \geq x \geq 0.05$ .

More preferably, the rare earth-doped ceria comprises  $\text{Ce}_{0.9}\text{Gd}_{0.1}\text{O}_{1.95}$ .

15

In another embodiment the electrolyte layer comprises a sintered layer of doped ceria.

The present invention further provides a fuel cell stack comprising a plurality of the above-described fuel cells.

20

In a preferred embodiment the present invention avoids the need to use brittle seals by using a metal foil substrate including a porous region fabricated by photo-chemical machining and cell compositions that allow operation at 500  $^{\circ}\text{C}$  or below. This relatively low operating temperature allows the use of commercially available compliant gaskets to seal the internal manifold configuration incorporated in the bipolar plates.

25

A preferred embodiment of the present invention will now be described hereinbelow by way of example only with reference to the accompanying drawings, in which:

30

Figure 1 illustrates a vertical sectional view of a fuel cell in accordance with a preferred embodiment of the present invention;

Figure 2 illustrates in enlarged scale a vertical sectional view of part of the fuel cell of Figure 1;

Figure 3 illustrates a plan view of the fuel cell of Figure 1, with a peripheral seal located thereon; and

Figure 4 illustrates projected I-V performance curves for single cell operation at 500 °C.

The fuel cell 1 includes a ferritic stainless steel substrate 3, in this embodiment a foil having a thickness of 100  $\mu\text{m}$ . In this embodiment the foil substrate 3 includes an active coating which provides protection from the operating environment and is such as to provide sufficient conductivity as to provide good current pathways and allow good interfacial contact. Preferred coatings include doped  $\text{LaMnO}_3$  (LMO) and  $\text{La}_{0.6}\text{Sr}_{0.4}\text{Co}_{0.2}\text{Fe}_{0.8}\text{O}_{3-x}$  (LSCF). One suitable ferritic stainless steel is a titanium/niobium stabilised stainless steel containing from 17.5 to 18.5 wt % Cr (European designation 1.4509). The foil substrate 3 includes a recess 5, in this embodiment of square shape, in one surface 3a thereof, a porous region 7 which is adjacent the recess 5 and includes a plurality of apertures 9 fluidly interconnecting the recess 5 and the other surface 3b of the foil substrate 3, and a non-porous region 8 bounding the porous region 7. In this embodiment the recess 5 and the apertures 9 in the foil substrate 3 are formed by photo-chemical machining (PCM) which allows excellent control over the shape and area of the porous region 7, the pore shape and size and the fractional porosity, as these parameters can be specified in the initial photo-lithograph image. Photo-chemical machining also provides a very flat surface for subsequent deposition processes in contrast to the rough surfaces of substrates fabricated from a sintered metal powder or felt, which surfaces would require the deposition of a relatively thick layer, typically greater than 30  $\mu\text{m}$ , to accommodate the

surface roughness. Further, photo-chemical machining is well-suited to mass production.

- The fuel cell 1 further includes a porous electrode layer 11, in this embodiment a cathode layer having a thickness of from 10 to 15  $\mu\text{m}$ , deposited in the recess 5 in the foil substrate 3 by any conventional ceramic processing technique, in particular screen printing and tape casting. In this embodiment the cathode layer 11 is fabricated from a cathode composition comprising a mixture of 60 vol % of LSCF powder and 40 vol % of  $\text{Ce}_{0.9}\text{Gd}_{0.1}\text{O}_{1.95}$  (CGO) powder, which, when sintered, provides a porous composite structure with three interpenetrating percolation networks (see V. Dusastre and J.A. Kilner, Solid State Ionics, 126, 1999, 163). The mean particle size of the powders of the cathode composition is in the range of from 0.1 to 10  $\mu\text{m}$ , preferably in the range of from 0.1 to 1  $\mu\text{m}$ .
- The fuel cell 1 further includes an electrolyte film 13, in this embodiment having a thickness of from 10 to 20  $\mu\text{m}$ , deposited over the cathode layer 11 so as to extend beyond the periphery thereof, again using conventional ceramic processing techniques. In this embodiment the electrolyte film 13 is fabricated from a composition comprising 98 mole % CGO and 2 mole %  $\text{Co}_3\text{O}_4$ . The materials of the cathode layer 11 and the electrolyte film 13 once deposited are then sintered at a sintering temperature of about 950  $^{\circ}\text{C}$  in a neutral atmosphere to prevent excessive oxidation of the foil substrate 3. This sintering temperature has been found to be sufficient, as disclosed in EP-A-1000913, to allow the CGO/ $\text{Co}_3\text{O}_4$  composition to sinter to provide a dense impermeable electrolyte film 13. By using CGO as the material for the electrolyte film 13, the thermal coefficients of expansion of the electrolyte film 13 and the foil substrate 3 are well matched, with CGO and ferritic stainless steel having coefficients of thermal expansion of  $12.5 \times 10^{-6} \text{ K}^{-1}$ , allowing the fuel cell 1 to withstand rapid temperature cycling which is a major advantage for small fuel cell stacks likely to encounter such operating conditions, such as incorporated in an APU of a vehicle.
- Also, significantly, the fuel cell 1 can be operated at temperatures of 500  $^{\circ}\text{C}$  or lower.

The fuel cell 1 further includes a further porous electrode layer 17, in this embodiment an anode layer having a thickness of from 10 to 25  $\mu\text{m}$ , deposited on the electrolyte film 13, again using conventional ceramic processing techniques. In this embodiment the anode layer 17 is fabricated from a composition comprising 50 vol % of NiO and 50 vol % of CGO. The material of the anode layer 17 once deposited is then sintered at a temperature of about 900 °C to provide a porous composite structure with three interpenetrating percolation networks.

The fuel cell 1 further includes a ferritic stainless steel bi-polar plate 19, having the same composition as the foil substrate 3, bonded to the non-porous, peripheral region 8 of the other surface 3b thereof. In bonding the periphery of the foil substrate 3 to the bi-polar plate 19, a seal is provided which acts to prevent the oxidant directly coming into contact with the fuel. In this embodiment the bi-polar plate 19 is for a simple cross-flow configuration with internal manifolds. In preferred embodiments the bi-polar plate 19 is machined from a thick plate or pressed from a metal sheet. Pressing from a thinner metal sheet has the advantage of reducing weight and thermal capacity. In preferred embodiments the peripheral region 8 of the foil substrate 3 is welded or brazed to one, in this embodiment the upper, surface 19a of the bi-polar plate 19 to provide an excellent electrical contact. In a stack, the other, lower surface 19b of the adjacent bi-polar plate 19 is pressed against the porous anode layer 17 to establish electrical contact. In a preferred embodiment a thin interfacial metal layer, for example a foil, mesh or felt, and preferably of Ni, is provided between each anode layer 17 and lower surface 19b of the adjacent bi-polar plate 19 to ensure good electrical contact and effective current distribution. In this embodiment the bi-polar plates 19 of the fuel cell stack are coupled by spring loaded rods extending through the periphery thereof. By the provision of spring-loaded rods, the bi-polar plates 19 of the fuel cell stack can be maintained under a predetermined pressure. In this embodiment the fuel cell stack includes a high-temperature gasket 21 located between and about the periphery of each of the bi-polar plates 19 to prevent direct mixing of the air and fuel supplies in the internal gas manifolds.

As will be appreciated, operation at 500 °C enables the use of commercial compliant gasket materials which greatly simplifies design, assembly and operation of the fuel cell stack compared to fuel cell stacks operated at higher temperatures which require brittle glass or glass-ceramic seals. One such gasket material is Unilon<sup>TM</sup> as available  
5 from James Walker, Woking, Surrey. A further benefit of operation at 500 °C resides in the observation that degradation, in particular corrosion of the stainless steel, is much reduced, allowing the fuel cell stack to be operated for very extended periods of time, typically in excess of 40,000 hours.

10 Figure 4 illustrates projected I-V performance curves for single cell operation at 500 °C. It will be significantly noted that specific power densities as high as 0.4 Wcm<sup>-2</sup> should be attainable at this temperature.

Finally, it will be understood that the present invention has been described in its  
15 preferred embodiment and can be modified in many different ways without departing from the scope of the invention as defined by the appended claims.

In one modification, the electrode layers 11, 17 could be formed of duplex or graded compositions to promote the electrode performance.

20

In another modification, the cathode and anode electrode layers 11, 17 could be reversed such that the anode layer 17 is located on the foil substrate 3 and the cathode layer 11 is located on the electrolyte layer 13.

25 In a further modification, the fuel cell 1 could be of other shape than square, for example, round.

Also, in a yet further modification, the present invention could be applied to a circular fuel cell design including a central manifold.

30

In a still further modification, the fuel cell 1 could be fabricated by co-sintering the material of the electrode layers 11, 17 and the electrolyte layer 13.



In another aspect, the present invention relates to the improvement of the cathode kinetics, that is, to decrease the effective cathodic resistance, by humidifying the oxidant gas. The presence of water vapour can promote the injection of oxygen ions  
5 into the cathode and electrolyte elements. This effect advantageously allows for operation at lower temperatures to achieve a given power density or increased power densities where operated at a given temperature. In preferred embodiments steam contents of at least 10 vol %, preferably in the range of 10 to 50 vol %, and more preferably in the range of 20 to 50 vol %, are utilised.

CLAIMS

1. A solid oxide fuel cell, comprising:  
a ferritic stainless steel substrate including a porous region and a non-porous region bounding the porous region;  
5 a ferritic stainless steel bi-polar plate located over one surface of the porous region of the substrate and being sealingly attached to the non-porous region of the substrate about the porous region thereof;  
a first electrode layer located over the other surface of the porous region of the substrate;  
10 an electrolyte layer located over the first electrode layer; and  
a second electrode layer located over the electrolyte layer.
2. The fuel cell of claim 1, wherein the ferritic stainless steel is a ferritic stainless steel containing no aluminium.
- 15 3. The fuel cell of claim 1 or 2, wherein the ferritic stainless steel is a titanium/niobium stabilised ferritic stainless steel.
4. The fuel cell of claim 3, wherein the ferritic stainless steel contains from about  
20 17.5 to 18.5 wt % Cr (European designation 1.4509).
5. The fuel cell of any of claims 1 to 4, wherein the substrate has a thickness of from about 50 to 250  $\mu\text{m}$ .
- 25 6. The fuel cell of claim 5, wherein the substrate has a thickness of from about 50 to 150  $\mu\text{m}$ .
7. The fuel cell of claim 6, wherein the substrate has a thickness of about 100  $\mu\text{m}$ .

8. The fuel cell of any of claims 1 to 7, wherein the porous region of the substrate includes a plurality of through apertures fluidly interconnecting the one and other surface of the substrate.
- 5 9. The fuel cell of claim 8, wherein the apertures are uniformly spaced.
- 10 10. The fuel cell of claim 8 or 9, wherein the apertures have a lateral dimension of from about 50 to 250  $\mu\text{m}$ .
- 10 11. The fuel cell of claim 10, wherein the apertures have a lateral dimension of from about 50 to 150  $\mu\text{m}$ .
12. The fuel cell of claim 11, wherein the apertures have a lateral dimension of about 100  $\mu\text{m}$ .
- 15 13. The fuel cell of any of claims 8 to 12, wherein the apertures comprise from about 40 to 65 area % of the porous region of the substrate.
14. The fuel cell of claim 13, wherein the apertures comprise from about 50 to 55 area % of the porous region of the substrate.
- 20 15. The fuel cell of any of claims 1 to 14, wherein the substrate includes an active coating of an electronically-conductive oxide.
- 25 16. The fuel cell of claim 15, wherein the active coating is a perovskite oxide mixed conductor.
17. The fuel cell of claim 16, wherein the perovskite oxide mixed conductor comprises  $\text{La}_{1-x}\text{Sr}_x\text{Co}_y\text{Fe}_{1-y}\text{O}_{3-\delta}$ , where  $0.5 \geq x \geq 0.2$  and  $0.3 \geq y \geq 0.1$ .
- 30 18. The fuel cell of claim 17, wherein the perovskite oxide mixed conductor comprises  $\text{La}_{0.6}\text{Sr}_{0.4}\text{Co}_{0.2}\text{Fe}_{0.8}\text{O}_{3-\delta}$ .

19. The fuel cell of claim 15, wherein the active coating comprises doped  $\text{LaMnO}_3$ .
20. The fuel cell of any of claims 1 to 19, wherein the substrate includes a recess in  
5 which the first electrode layer is at least partially located.
21. The fuel cell of any of claims 1 to 20, wherein the substrate comprises a foil.
22. The fuel cell of any of claims 1 to 21, wherein the substrate is a photo-  
10 chemically machined substrate.
23. The fuel cell of any of claims 1 to 22, wherein one or both of the first and second electrode layers has a thickness of from about 10 to 25  $\mu\text{m}$ .
- 15 24. The fuel cell of claim 23, wherein one or both of the first and second electrode layers has a thickness of from about 10 to 15  $\mu\text{m}$ .
25. The fuel cell of any of claims 1 to 24, wherein one or both of the first and second electrode layers is a sintered material.
- 20 26. The fuel cell of claim 25, wherein one of the first and second electrode layers comprises a sintered powdered mixture of perovskite oxide mixed conductor and rare earth-doped ceria.
- 25 27. The fuel cell of claim 25 or 26, wherein the powdered mixture comprises about 60 vol % of perovskite oxide mixed conductor and about 40 vol % of rare earth-doped ceria.
- 30 28. The fuel cell of claim 27, wherein the perovskite oxide mixed conductor comprises  $\text{La}_{1-x}\text{Sr}_x\text{Co}_y\text{Fe}_{1-y}\text{O}_{3-\delta}$ , where  $0.5 \geq x \geq 0.2$  and  $0.3 \geq y \geq 0.1$ .

29. The fuel cell of claim 28, wherein the perovskite oxide mixed conductor comprises  $\text{La}_{0.6}\text{Sr}_{0.4}\text{Co}_{0.2}\text{Fe}_{0.8}\text{O}_{3-\delta}$ .
30. The fuel cell of any of claims 26 to 29, wherein the rare earth-doped ceria comprises  $\text{Ce}_{1-x}\text{RE}_x\text{O}_{2-x/2}$ , where RE is a rare earth and  $0.3 \geq x \geq 0.05$ .
31. The fuel cell of claim 30, wherein the rare earth-doped ceria comprises  $\text{Ce}_{0.9}\text{Gd}_{0.1}\text{O}_{1.95}$ .
32. The fuel cell of any of claims 26 to 31, wherein the one of the first and second electrode layers is the first electrode layer provided as a cathode layer.
33. The fuel cell of any of claims 26 to 32, wherein the other of the first and second electrode layers comprises a sintered powdered mixture of NiO and rare earth-doped ceria.
34. The fuel cell of claim 33, wherein the powdered mixture comprises about 50 vol % of NiO and about 50 vol % of rare earth-doped ceria.
35. The fuel cell of claim 33 or 34, wherein the rare earth-doped ceria comprises  $\text{Ce}_{1-x}\text{RE}_x\text{O}_{2-x/2}$ , where RE is a rare earth and  $0.3 \geq x \geq 0.05$ .
36. The fuel cell of any of claims 33 to 35, wherein the other of the first and second electrode layers is the second electrode layer provided as an anode layer.
37. The fuel cell of claim 36, wherein the rare earth-doped ceria comprises  $\text{Ce}_{0.9}\text{Gd}_{0.1}\text{O}_{1.95}$ .
38. The fuel cell of any of claims 1 to 37, wherein the electrolyte layer has a thickness of from about 10 to 20  $\mu\text{m}$ .

39. The fuel cell of any of claims 1 to 38, wherein the electrolyte layer comprises a sintered powdered mixture of rare earth-doped ceria and  $\text{Co}_3\text{O}_4$ .
40. The fuel cell of claim 39, wherein the sintered powdered mixture comprises about 98 mole % rare earth-doped ceria and about 2 mole %  $\text{Co}_3\text{O}_4$ .
41. The fuel cell of claim 39 or 40, wherein the rare earth-doped ceria comprises  $\text{Ce}_{1-x}\text{RE}_x\text{O}_{2-x/2}$ , where RE is a rare earth and  $0.3 \geq x \geq 0.05$ .
42. The fuel cell of claim 41, wherein the rare earth-doped ceria comprises  $\text{Ce}_{0.9}\text{Gd}_{0.1}\text{O}_{1.95}$ .
43. The fuel cell of any of claims 1 to 38, wherein the electrolyte layer comprises a sintered layer of doped ceria.
44. A fuel cell stack comprising a plurality of the fuel cells of any of claims 1 to 43.
45. A solid oxide fuel cell substantially as hereinbefore described with reference to the accompanying drawings.

**ABSTRACT****FUEL CELLS**

A solid oxide fuel cell, comprising: a ferritic stainless steel substrate including a porous region and a non-porous region bounding the porous region; a ferritic stainless steel bi-polar plate located over one surface of the porous region of the substrate and being sealingly attached to the non-porous region of the substrate about the porous region thereof; a first electrode layer located over the other surface of the porous region of the substrate; an electrolyte layer located over the first electrode layer; and a second electrode layer located over the electrolyte layer.

10

[Figure 1]

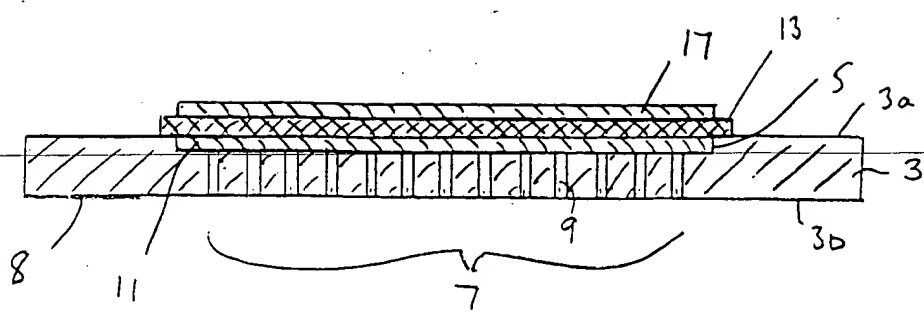


Fig. 2

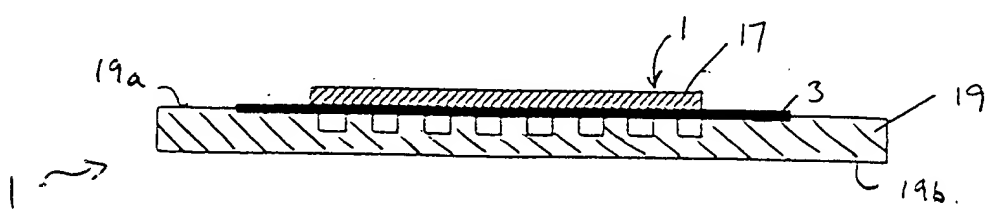


Fig. 1

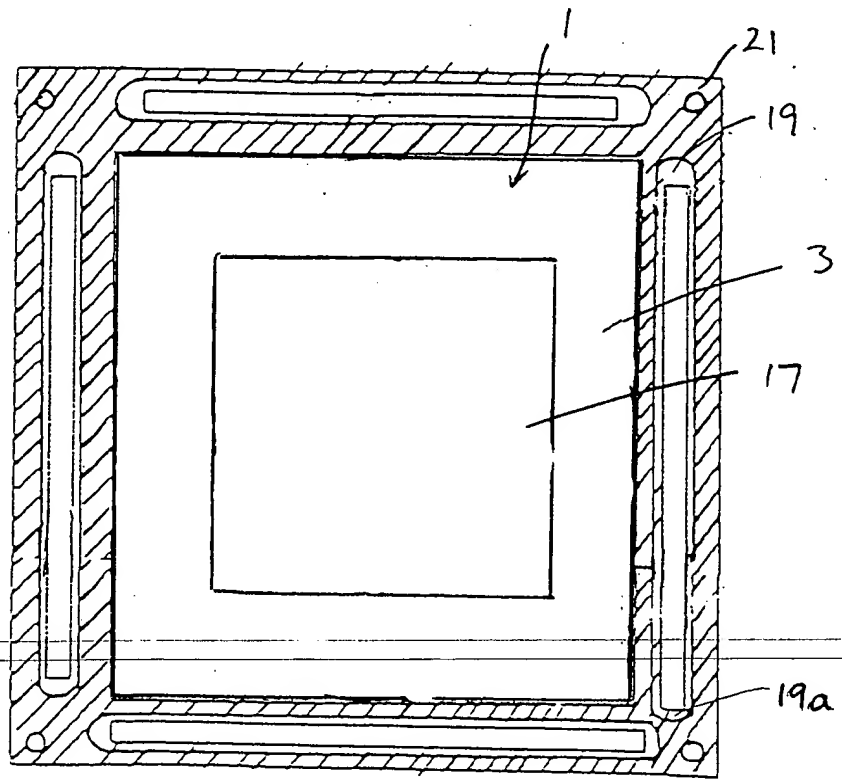


Fig. 3



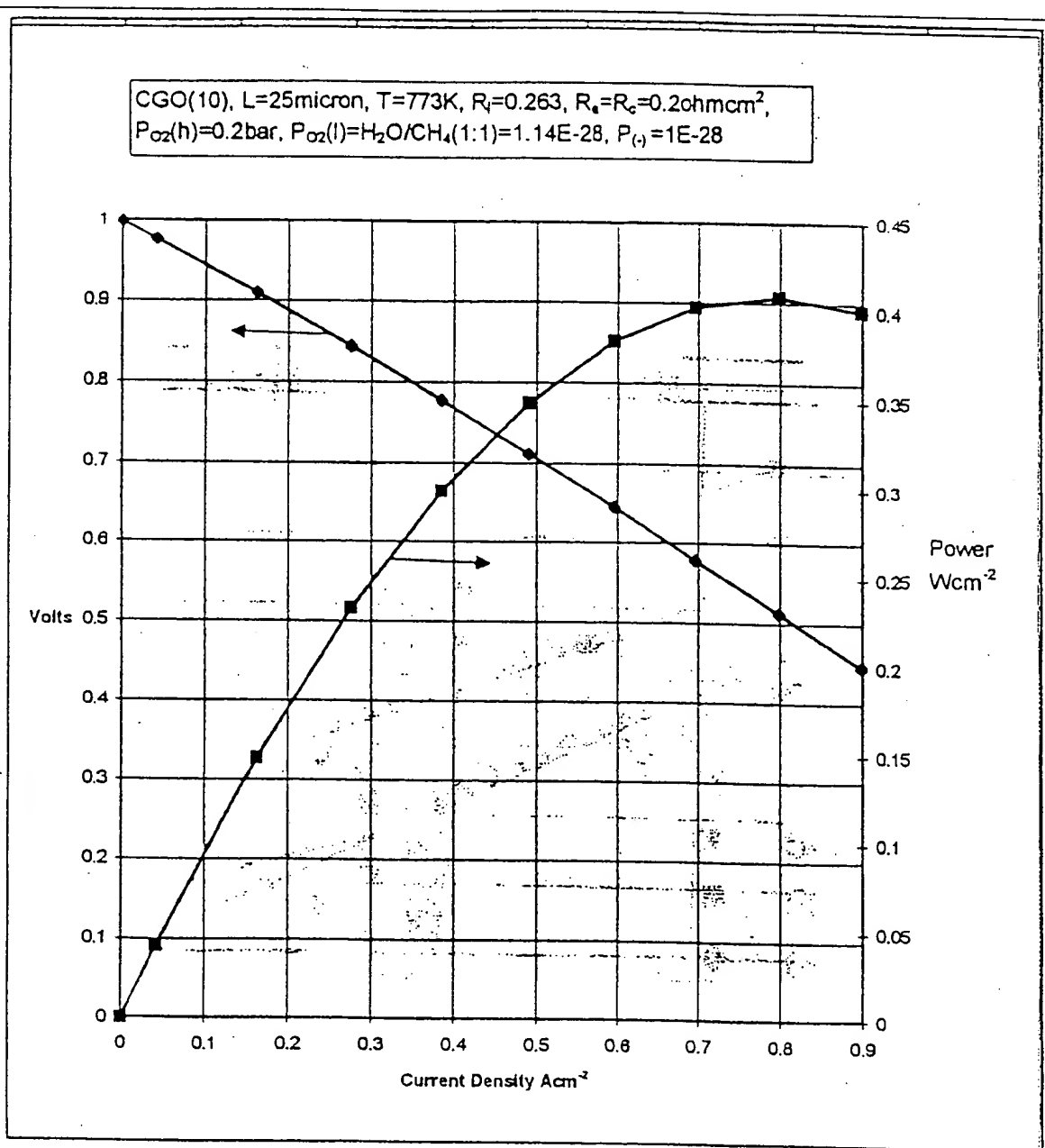


Fig. 4